

Radioactive decay and nuclear binding energy

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet

Name: _____ Date: _____ Class: _____

These twenty problems cover decay equations, the decay law, half-life, mass defect and binding energy, and the energy released in fission and fusion. They start with nuclear notation and move to multi-step data analysis and estimates of the energy in a kilogram of fuel. They suit A Level, IB Physics, CBSE class 12 and WAEC senior students. Use $c = 3.00 \times 10^8$ m/s and $1 \text{ u} = 931.5 \text{ MeV}/c^2$ unless a problem says otherwise.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB E.3-E.5

Problem 1 Three kinds of radiation (easy)

Imani in Mombasa revises the three types of radiation from nuclei.

1. State what an alpha particle is and the changes it causes in A and Z.
2. State what happens inside the nucleus in beta-minus decay and the change in Z.
3. State the changes in A and Z when a gamma photon is emitted.

Problem 2 Radium alpha decay (easy)

Radium-226 ($Z = 88$) emits an alpha particle and becomes radon ($Z = 86$). Determine the mass number of the radon nuclide and write the nuclear equation in words.

Problem 3 Cobalt-60 beta decay (easy)

Cobalt-60 ($Z = 27$) decays by beta-minus emission to an isotope of nickel. Find the mass number and proton number of the nickel nuclide.

Problem 4 Three half-lives of cobalt-60 (easy)

A source for sterilising spices in Pune has an activity of 8.0×10^6 Bq. Cobalt-60 has a half-life of 5.27 years. Calculate the activity after 15.8 years.

Problem 5 Mass and energy units (easy)

Convert the following.

1. A mass defect of 0.0305 u into MeV ($1 \text{ u} = 931.5 \text{ MeV}/c^2$).
2. An energy of 4.0 MeV into joules ($1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$).

Problem 6 Decay constant of caesium-137 (medium)

Chiamaka in Lagos reads that caesium-137 has a half-life of 30.1 years. Calculate its decay constant in s^{-1} . Use $1 \text{ year} = 3.156 \times 10^7 \text{ s}$.

Problem 7 Activity of a radon sample (medium)

A sealed chamber in Leeds holds 2.0×10^{15} nuclei of radon-222, of half-life 3.82 days.

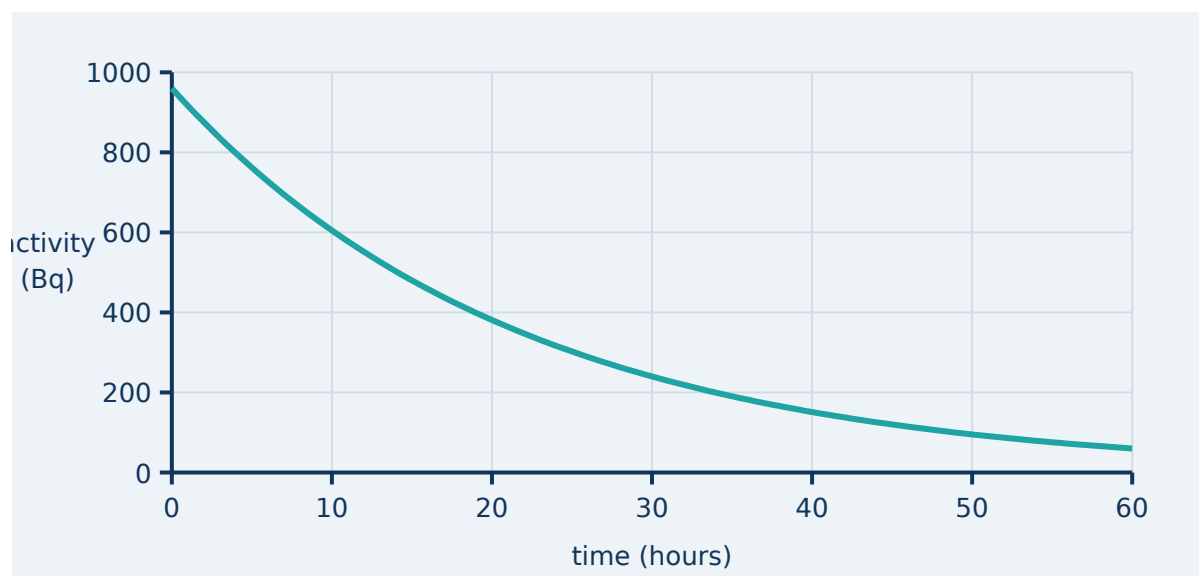
1. Calculate the decay constant in s^{-1} .
2. Calculate the activity.

Problem 8 Phosphorus-32 tracer (medium)

Wanjiru in Nairobi uses phosphorus-32 (half-life 14.3 days) as a tracer for fertiliser uptake in maize. Calculate the percentage of the phosphorus-32 left after 30 days.

Problem 9 Reading a decay graph (medium)

The graph shows the activity of a sodium-24 sample.



Activity of the sample against time.

1. Use the graph to find the half-life.
2. Find the activity at 45 hours.
3. Find the time at which the activity falls to 240 Bq.

Problem 10 A PET tracer (medium)

Kofi in Accra learns that fluorine-18, used in PET scans, has a half-life of 110 minutes. A dose is delivered at 2000 MBq. Calculate how long it takes for the activity to fall to 300 MBq.

Problem 11 Binding energy of the deuteron (medium)

Use atomic masses: hydrogen atom 1.007825 u, neutron 1.008665 u, deuterium atom 2.014102 u. Calculate the mass defect, the binding energy in MeV and the binding energy per nucleon.

Problem 12 A milligram of mass (medium)

Aarav in Pune imagines that 1.0 mg of matter is converted completely to energy. Use $c = 3.00 \times 10^8$ m/s.

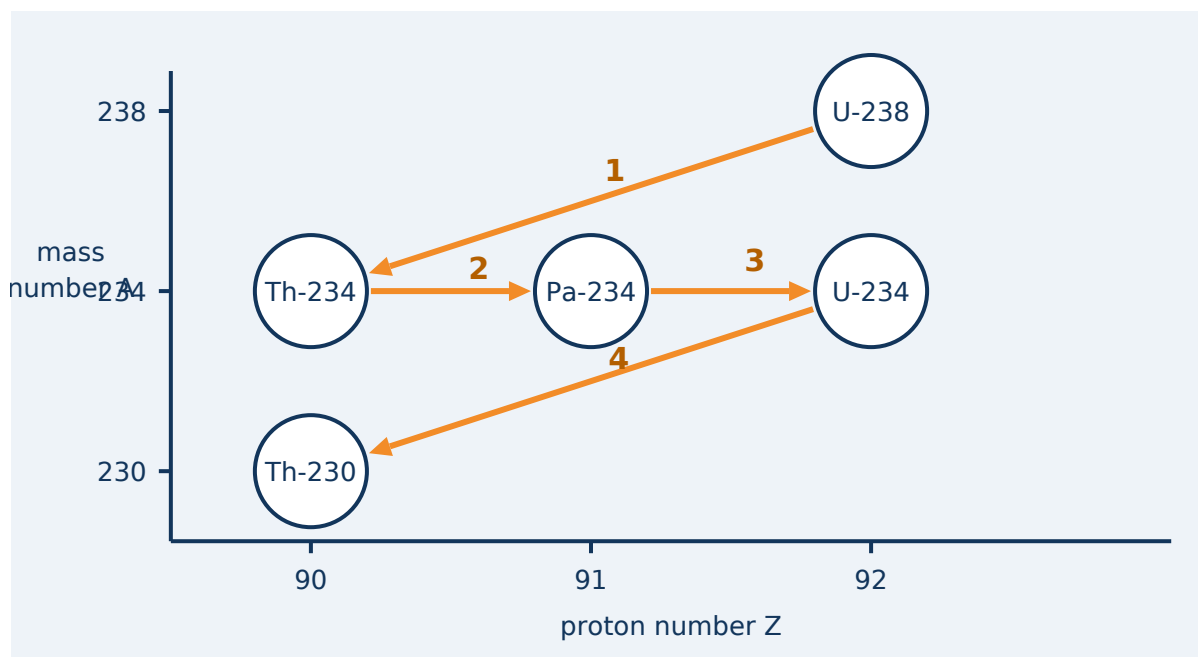
1. Calculate the energy released in J.
2. Convert it to kWh ($1 \text{ kWh} = 3.6 \times 10^6$ J).
3. A home uses 5.0 kWh per day. Calculate how many years this energy would supply it.

Problem 13 Energy of an alpha decay (medium)

Use atomic masses: radium-226 226.02541 u, radon-222 222.01758 u, helium-4 4.00260 u. Calculate the energy released in the decay $\text{radium-226} \rightarrow \text{radon-222} + \text{helium-4}$, in MeV.

Problem 14 Reading a decay series (medium)

The grid shows the start of a radioactive series, with mass number A against proton number Z.



Four decay steps, numbered 1 to 4.

1. Name the type of decay at each step 1 to 4.
2. Calculate how many neutrons the nuclide uranium-238 has ($Z = 92$).
3. State the relation between uranium-238 and uranium-234.

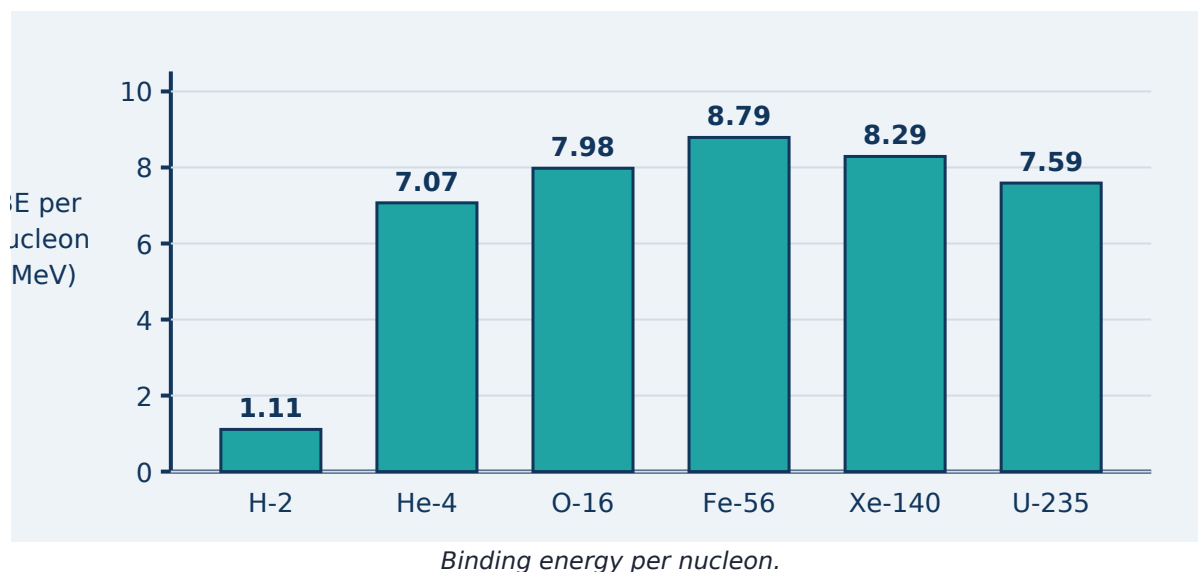
Problem 15 Spot the errors (medium)

Diego in Texas wrote three statements. Explain why each is wrong and correct it.

1. "After two half-lives all the nuclei have decayed."
2. "In beta-minus decay the mass number falls by one."
3. "Binding energy is the energy given out when a nucleus is pulled apart."

Problem 16 Reading a binding energy chart (hard)

The bar chart shows binding energy per nucleon for some nuclides.



1. State which nuclide in the chart is the most stable and explain why.
2. Calculate the total binding energy of iron-56 in MeV and the mass defect in u.
3. Use the chart to calculate the energy released when two hydrogen-2 nuclei fuse into one helium-4 nucleus.

Problem 17 Fission of uranium-235 (hard)

A neutron strikes uranium-235 ($Z = 92$) and the nucleus splits into xenon-140 ($Z = 54$), strontium-94 ($Z = 38$) and neutrons. The binding energies per nucleon are: uranium-235 7.59 MeV, xenon-140 8.29 MeV, strontium-94 8.59 MeV. Use $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$.

1. Find the number of neutrons released, by balancing A and Z.
2. Calculate the energy released in one fission in MeV.
3. Calculate the energy released when 1.00 kg of uranium-235 undergoes fission, in joules ($1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$).

Problem 18 Fusion fuel per kilogram (hard)

A deuterium nucleus (H-2, 1.11 MeV per nucleon) and a tritium nucleus (H-3, 2.83 MeV per nucleon) fuse to form helium-4 (7.07 MeV per nucleon) and a neutron. Use $1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$ and $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$.

1. Calculate the energy released by one reaction in MeV.

2. Calculate the energy released per kilogram of deuterium-tritium fuel, taking the mass of one reacting pair as 5.00 u.
3. Fission of uranium-235 gives about 8×10^{13} J per kg. Compare the two.

Problem 19 A straight line from a decay (hard)

Imani in Mombasa records the activity of a short-lived sample at two-hour intervals.

Time t (h)	0	2	4	6	8
Activity A (kBq)	80.0	63.5	50.4	40.0	31.8

1. Explain why a graph of $\ln A$ against t is a straight line.
2. Calculate $\ln A$ for $t = 0$ and for $t = 8$ h, and find the gradient between these points.
3. Determine the decay constant and the half-life.

Problem 20 A gram of radium (hard)

Radium-226 has a half-life of 1600 years. Use $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$, molar mass 226 g/mol and $1 \text{ year} = 3.156 \times 10^7 \text{ s}$.

1. Calculate the number of nuclei in 1.00 g.
2. Calculate the decay constant in s^{-1} and the activity of 1.00 g.
3. Calculate the activity of this sample after 400 years.